AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

Note.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

CCLXI.

(Vol. XII.—August, 1883.)

ON THE CURRENT METER, TOGETHER WITH A REASON WHY THE MAXIMUM VELOCITY OF WATER FLOWING IN OPEN CHANNELS IS BELOW THE SURFACE.

By F. P. Stearns, M. Am. Soc. C. E.

Read at the Annual Convention, St. Paul, Minn., June 21st, 1883.

In a paper* presented to the Society in May of last year, mention was made of a current-meter used on the Boston Water Works, and a brief statement was given of the results of some experiments made to test its accuracy. This meter was designed, and the experiments were made, under the supervision of Mr. A. Fteley, M. Am. Soc. C. E., Resident Engineer in charge of the works.

As an incidental feature of the current-meter experiments, observations were made (see Plate XX., p. 324), which showed the distribution of velocities at different points in the cross-section of the Sudbury Conduit.

This paper was, at first, intended to relate only to the current-meter, but the introduction of the plate, just referred to, suggested the addition of some remarks on the subject indicated by the second part of the title.

The first part of the title is somewhat too general, as the paper relates only to current-meters with helicoidal vanes, and more particularly to the instrument as applied to the accurate measurement of the flow in channels of moderate size.

*** Description of some Experiments on the Flow of Water made during the Construction of Works for Conveying the Water of Sudbury River to Boston ; by A. Fteley and F. P. Stearns. Transactions of the Society, Jan.—March, 1883.**

THE CURRENT-METER.

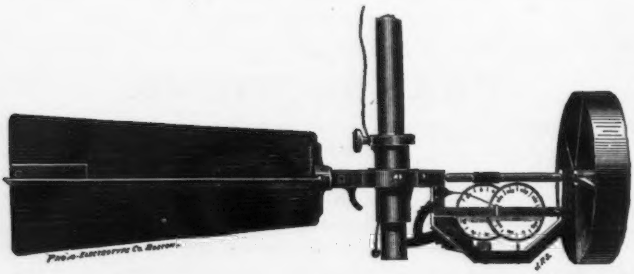


Fig. 1.

Two meters were used. The first one, illustrated by the accompanying cut,* was copied with but few changes from meter No. 1, used by the late Gen. T. G. Ellis, M. Am. Soc. C. E., during his surveys of the Connecticut River.†

This instrument was frequently used for several years to measure the flow of Sudbury River and of other channels; and with the exception that it did not measure very low velocities, it operated in a satisfactory manner, and its results appeared to be trustworthy.

After about five years' use of the first instrument a second one was designed, which embodied the improvements suggested by experience and a study of the requisites of a good meter. It is this second instrument, known as meter No. 2, which will be referred to in this paper; the cut of the first instrument being introduced to show, by comparison, the changes made in designing the second one.

Before proceeding with a description of the meter, the general requisites of a good current-meter will be considered. They are conceived to be as follows:

1. The friction of its bearings should be so small that low velocities will be registered.

2. The meter should be so constructed that its rate will not vary, requiring:

* This cut, which was made from a photograph of the first meter, is kindly loaned by Messrs. Buff and Berger, the makers of both instruments.

† Appendix B 14 of the Annual Report of the Chief of Engineers for 1878.

(*a.*) The vanes and axis to be protected from liability to accident.

(*b.*) The amount of friction of the bearings to be practically constant.

3. The rate should be the same in clear water and in water containing sediment, a result which can be attained, approximately, by making the total amount of friction so small that a slight change in it will be unimportant.

4. The wheel should be so protected that it can be used near the sides and bottoms of channels.

5. The meter should register the same number of revolutions when held in a current, whether steady or variable, that it does when moved uniformly with the same mean velocity through still water.

6. It is desirable to have a meter record fractions of a revolution, as such an arrangement sometimes reduces the time required for observations.

7. The meter should be so strong that it will not be injured when struck by small floating substances.

8. The apparatus for connecting and disconnecting the recording wheels should work with the least possibility of failure.

9. The construction of the instrument should be such that leaves and straws catching upon it will not seriously impede the movement of the wheel.

Description of Meter No. 2.

The general design of the instrument is shown by Plate XV.

The most important change from the design of instruments previously made is in the frame, which in this instrument is situated both behind and in front of the wheel; an arrangement permitting the use of two end bearings, instead of one end and one sleeve bearing, and on account of the protection afforded, the use of a very light wheel and axis. These changes reduced the friction very much, so that the second meter registered with one-fourth of the velocity (one-sixteenth of the pressure) required to turn the other.

Two wheels were provided, each 0.30 feet in diameter and 0.078 feet in width. The wheel shown with the meter in the illustration has eight helicoidal vanes with a pitch of 0.771 feet; the other has ten helicoidal vanes, one-half with a pitch of 0.785 feet alternating with the other half having a pitch of 0.985 feet.

The axis turns in agate bearings and is made of a hard composition metal, which does not rust from being wet.

The centre of gravity of the wheel and axis is very exactly in the centre of the axis. The motion of the wheel is transmitted by gearing to the recording wheels placed at the top of the instrument, where they can be conveniently read when the instrument is used in a man-hole or any other place where the light comes from above, or where limited room will not permit the meter to be turned on its side. This arrangement also proved advantageous when rating the instrument, as readings could be taken by raising the meter vertically a few inches, instead of taking it from the water and turning it, as would have been necessary had the recording wheels been on the side. At the gear where the recording wheels were connected and disconnected, each tooth represented a half revolution ; consequently the nearest half revolution at the beginning of an experiment was recorded. At the end of an experiment there was no error in the record, since the revolution of the recording wheels was stopped immediately by throwing them against a spring. The wheels were thrown into and out of gear by mechanism so arranged that one pull of a string threw them into gear, while a second pull threw them out. The band around the wheel is a feature which appears in many of the instruments made at the present day, but was not used in the earlier forms of the instrument, and has not been adopted in the meters designed more recently by Harlacher, Révy, Deacon and Shaw. From a practical point of view it is a very valuable feature, as it holds the ends of the vanes securely and prevents change in their form from slight accidents, and consequent change in the rate of the instrument. As a further precaution against accident, and to allow readings to be taken very near the side of a channel, a strong wire was put around the wheel a short distance outside of the band.

When in use the meter was fastened to the end of a brass tube which served as a handle. A line along the back of the tube indicated the direction of the axis when the instrument could not be seen. No tail was attached, as experience had shown that it has no value on a meter held by a rigid handle.

Rating a Meter.

When a meter is used in a current, the record gives the number of revolutions ; to reduce revolutions to velocity, it is necessary that the

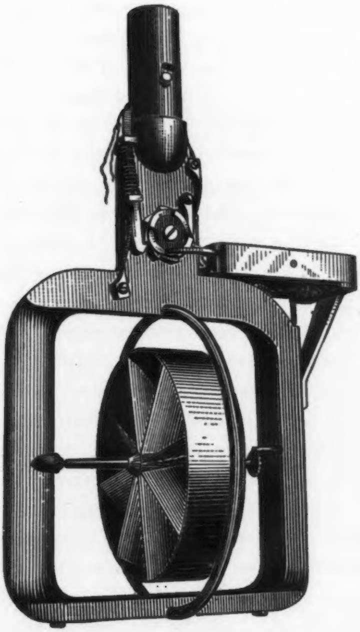


PLATE XV.

TRANS. AM. SOC. CIV. ENGRS.
VOL. XII., No. CCLXI.

STEARNS

ON THE CURRENT-METER.

instrument should first be rated. This is usually done by moving it at a uniform rate through still water, the distance and time being noted.

For rating meter No. 2, a simple, temporary apparatus was constructed in the Sudbury Conduit, with which accurate results were rapidly obtained.

Plate XVI. shows most of the apparatus used. Fig. 1 is a cross-section of the track, showing its position in the conduit. The length of the track was 140 feet; 100 feet in the middle of this length was used as a course for observations, the remaining portions, 20 feet at either end, being lengths in which a uniform movement of the meter was acquired.

Figs. 2 and 3 show respectively a back and end view of the car in position on the track. The arrangement for attaching the meter to the car was such that the meter could be faced in either direction, and fastened with its axis parallel with the track. A stop-watch, *A*, was fastened to the car near its top, and was used to record the time occupied in passing the length of the course. The recording wheels of the meter were connected and disconnected automatically at the beginning and end of the course by apparatus arranged as follows:

A *T*-shaped piece, *B*, was fastened to the car by a single screw near its middle, on which it turned freely. From both ends of the top of this piece, cords, *C*, *C*, led to one end of the lever, *D*, which was connected at its other end with the mechanism on the meter by the cord *E*.

At each end of the course a pin projected from the side of the track, and as the car passed in either direction the *T*-shaped piece struck the pin and rotated, drawing down on one or the other of the cords, *C*, *C*, thus operating the lever *D*, and through it the cord leading to the meter. The apparatus was brought back to its original position by a strong rubber band, *F*.

The car was pushed by hand, and, to secure uniformity of movement, the strokes of a small bell, *G*, sounded by one of the car wheels at each revolution, were made to coincide with the ticks of a metronome. With small velocities the bell was sounded two or four times at each revolution, and with the smallest velocities the car was drawn over a shorter course by a cord winding upon a small axle at a uniform rate.

Two guards, *H*, *H*, were attached near the ends of the car to prevent injury to the meter should the car wheels run off the track.

The water in the conduit was controlled by a dam, and there was no current.

Track and Car used in the Sudbury Conduit for rating Current Meter No. 2.

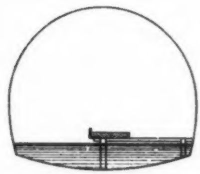


FIG. 1.

Scale of feet.

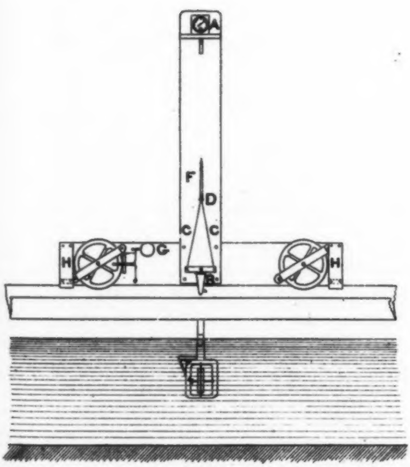


FIG. 2.

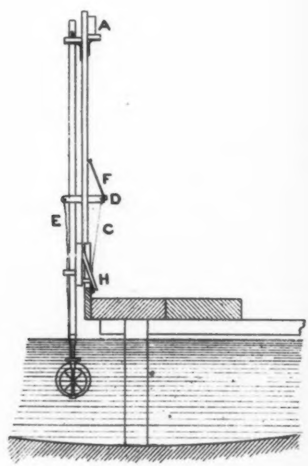


FIG. 3.

Scale of feet.

PLATE XVI.
TRANS. AM. SOC. CIV. ENGRS.
VOL XII Nº CCLXI
STEARNS
ON THE CURRENT METER

It will be observed that the car, running on a single rail, will not support itself in a vertical position; on this account a car with four wheels, running on a track with two rails, would be somewhat more convenient. The accuracy of the rating would probably be the same in either case.

The results of the rating of the two wheels are shown by the accompanying diagram (Plate XVII.), which explains itself.

The rating with slow velocities is omitted to avoid confusion in the drawing.

The vanes of the wheels, being helicoidal, would, theoretically, *i. e.*, if there were no slips, make one revolution when advanced a distance equal to their pitch; consequently from the data already given about the pitch of the vanes we find the theoretical number of revolutions of the eight-vane wheel per foot advance to be 1.296, and of the two sets of vanes of the ten-vane wheel to be 1.273 and 1.015, making an average of 1.144. The theoretical numbers of revolutions here given are represented on the diagram by straight lines marked *A*, *B* and *C*.

It will be noticed that the curves of rating are quite similar in form.

The eight-vane wheel begins to revolve with a velocity of 0.104 feet per second; with a velocity of 0.30 feet it gives 0.950 revolutions to each foot advanced (73 per cent. of the theoretical number); with velocities of 2.2 feet and of 6.5 feet it gives 1.237 revolutions (95½ per cent. of the theoretical number), while with velocities between these the number of revolutions is smaller, causing a sag in the curve. This peculiar sag may also be seen in the curve of the ten-vane wheel, and it appeared in the curve of meter No. 1; the cause of it is not known.

The ten-vane wheel began to revolve with a velocity of 0.094 feet per second.

The close agreement between the different observations and the curves indicates that a meter may be rated with a high degree of accuracy. A variation of about one per cent. is represented by the diameter of the circles, and it may be noticed that the centres of but few circles are distant from the curve even one-half of this amount. The single observations represented by the crosses are more irregular; yet there are but few instances in which the error exceeds one per cent.

Miscellaneous Observations about Rating a Meter.

The rating of meter No. 2, which included 196 observations with the ten-vane, and 147 observations with the eight-vane wheel, was done by two persons in four days, notwithstanding some of the time was oc-

cupied in adding apparatus for drawing the car at a uniform rate with slow velocities, and in making experiments upon irregular and angular movements, to be described further on.

An extract from the note-book is given below as a sample of the agreement of successive observations with nearly the same velocity. It is a fair specimen of the results obtained with ordinary velocities:

RATING OF THE EIGHT-VANE WHEEL, JANUARY 25TH, 1879.

1 Revolutions per 100 Feet.	2 Time per 100 Feet. Seconds.	3 Velocity in Feet per Second.	
119.8	88.0	1.136	
120.4	89.0	1.124	
120.1	88.5	1.130	Averages.
121.1	75.0	1.333	
121.4	76.6	1.305	
121.25	75.8	1.319	Averages.
122.4	63.0	1.587	
122.4	67.6	1 479	
122.2	65.8	1.520	
122.33	65.5	1 529	Averages.
122.8	61.8	1 618	
122.7	61.8	1 618	
122.75	61.8	1.618	Averages.
123.3	53.0	1.887	
123 6	52.2	1.916	
123.45	52.6	1.901	Averages.

The quantities in the first column are differences between the readings of the counting wheels at the beginnings and ends of experiments. The quantities in the second column are the direct readings of the stop-watch. The quantities in the third column were readily obtained from those in the second by the use of a table of reciprocals. It will be seen that the choice of a course of odd length would not have allowed the use of the table, and, consequently, would have increased the office work very much.

Columns 1 and 3 furnish all the data required to plot a curve similar to those shown on Plate XVII. Such a curve, however, though best suited to show the results of the rating, is not suitable for practical use, and another curve must be constructed which will have the same abscissæ, but in which the ordinates will be revolutions per second instead of revolutions per foot advance. These new ordinates are obtained by multiplying the ordinates of the first curve by the corresponding abscissæ, a work involving but little labor when the points are so chosen that one of the multipliers is an even unit or tenth.

Before rating a new meter, it is well to place it in a current where the wheel may revolve long enough to wear the bearings to the condition they will assume when in use.

No oil should be used, as it is gradually removed by the water, and a variable friction is caused thereby.

TESTS OF THE ACCURACY OF A METER WHEN USED TO MEASURE THE VELOCITY OF A CURRENT.

The rating, already described, gives the relation between revolutions and velocity, when the meter is moved through still water at a uniform rate. The question now arises, is this relation the same when the meter is stationary and the water flows past it? The conditions may, at first thought, seem to be identical, but, on closer examination, appreciable differences in them will be found; not that it makes any difference in the impact on the vanes whether it is the meter or the water that moves, but because water in a channel does not move forward uniformly in parallel lines, nor is the velocity in different parts of the channel the same. On the contrary, the flow past any point in a channel may be variable in velocity and not parallel with the axis of the current, and the velocities at two points not further apart than the diameter of the wheel of the current-meter may be quite different.

To determine the effect of these different conditions, and whether a meter will give correct results as used in practice, many experiments were made; the subject was, however, first examined theoretically, as a guide to making the experiments. Following the same order in this paper, the theory will first be discussed, and the results obtained from the experiments will be presented later.

Some terms which have proved convenient for use in connection with meter measurements are defined below:

Point Measurement.—A measurement in which the mean velocity is deduced from observed velocities at each of several points in the cross-section of a channel.

Integrated Measurement.—A measurement in which the mean velocity is determined at one operation by moving the meter through all parts of a cross-section in such a manner that it moves through equal divisions in equal times.

Rate of Integrating.—The rate of speed at which the meter is moved in the cross-section of a channel while integrating.

*Forward Velocity.**—The component of the actual velocity at any point which is parallel with the axis of the current; also, when moving a meter through still water, the component of the velocity of the motion which is parallel with the axis of the meter.

Side Velocity.—The component of the actual velocity which is perpendicular to the axis of the current; also, when moving a meter through still water, the component of the velocity of the motion which is parallel with the axis of the meter.

Comparison of Conditions of Rating and Measuring.

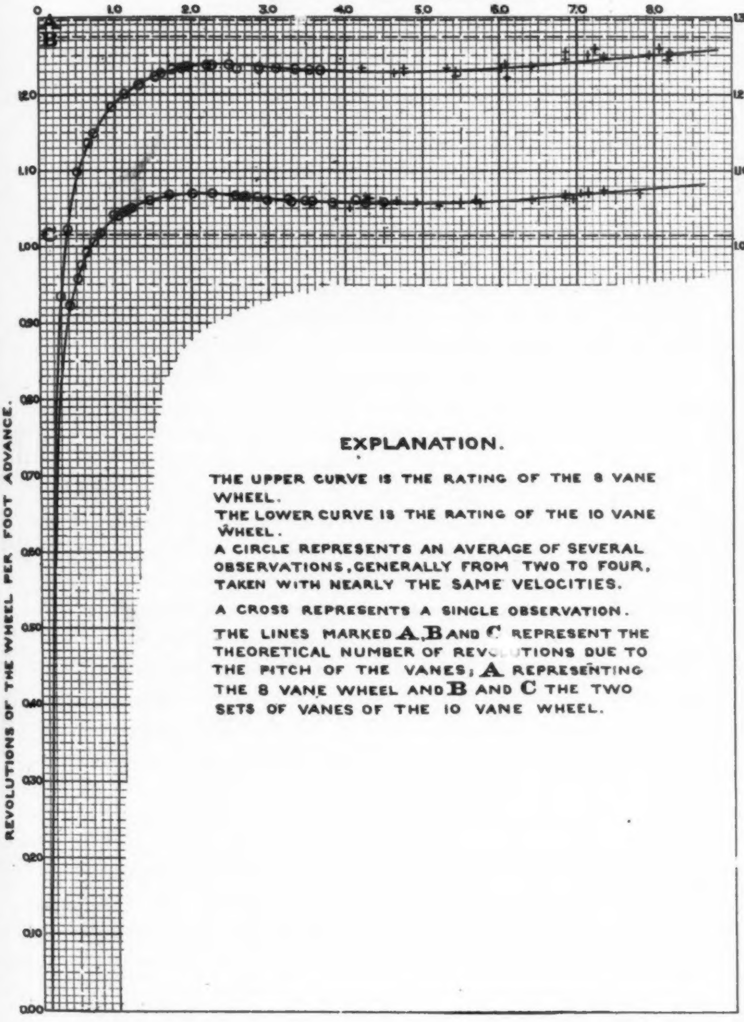
Using as a basis for comparison the conditions existing during the uniform movement of a meter through still water in the direction of its axis, the differences which are found when measuring in a channel will be considered in some detail:

1. *The velocity is variable.*

Some of the experiments of Mr. James B. Francis, Past President Am. Soc. C. E., showed that the variations in the velocity in particular parts of a flume were very marked, even when the mean velocity was

* A term used by Major Allan Cunningham.

Diagram showing rating of Current Meter No. 2.



EXPLANATION.

THE UPPER CURVE IS THE RATING OF THE 8 VANE WHEEL.

THE LOWER CURVE IS THE RATING OF THE 10 VANE WHEEL.

A CIRCLE REPRESENTS AN AVERAGE OF SEVERAL OBSERVATIONS, GENERALLY FROM TWO TO FOUR, TAKEN WITH NEARLY THE SAME VELOCITIES.

A CROSS REPRESENTS A SINGLE OBSERVATION.

THE LINES MARKED **A**, **B** AND **C** REPRESENT THE THEORETICAL NUMBER OF REVOLUTIONS DUE TO THE PITCH OF THE VANES; **A** REPRESENTING THE 8 VANE WHEEL AND **B** AND **C** THE TWO SETS OF VANES OF THE 10 VANE WHEEL.

PLATE XVII.
TRANS. AM. SOC. CIV. ENGRS.
VOL XII Nº CCLXI
STEARNS
ON THE CURRENT METER

constant. He says:* "The variations extend from 8.57 per cent. above the mean to 11.40 per cent. below; the average variation in thirty observations in different parts of the width of the flume being about 3.12 per cent.

These variations are deduced from the mean velocities of the floating tubes through a course of 70 feet; the variations in some parts of the course must have largely exceeded these averages. The variations in velocity just described are deduced from exact observations in different parts of the width of the stream; similar, and probably greater variations must occur in different parts of the depth."

Major Cunningham remarks:† "It was found in the Roorkee experiments that the range of velocities deduced from a number of similar floats run in rapid succession over nearly the same float-course was commonly 20 per cent. of the mean. In some of Harlacher's experiments a current-meter was fitted with electric connections so as to record every revolution; the variations amount to from 20 per cent. in surface velocities to 50 per cent. in bed velocities in a few seconds."

These quotations show that the flow of water is not at all steady, and they indicate the amount of variation which may occur.

In the case of an integrated measurement, the water will strike the meter with a variable velocity, even if the flow is steady, on account of the passage of the meter through the different parts of the channel where the velocities are not the same.

The effect of variable velocities upon a meter measurement may be tested by comparing an ordinary rating with one made by moving the car at an irregular rate; also by comparing meter measurements of steady and variable currents when the volume flowing is known or constant.

2. *The water may strike the meter at an angle with its axis.*

This may occur from the presence of boils, whirls and cross-currents, or because the axis of the meter is not held parallel with the axis of the current; in the case of an integrated measurement it is sure to occur, because the velocity and direction with which the water strikes the meter are the resultant of the forward velocity of the water and the transverse movement of the meter.

---

* Transactions of the Society, May, 1878, page 111.

† Recent Hydraulic Experiments, by Major Allan Cunningham, R. E. Minutes of Proceedings, Inst. C. E., Vol. LXXI., p. 10.

The effect of this angular movement may be tested by rating the meter when its axis is at an angle with the track of the rating machine, and by comparing meter measurements taken by integrating at different rates.

3. *The water may strike opposite vanes of a wheel with different velocities.* This may occur from irregular flow, and is sure to occur near the bottom and sides of a channel, where the velocities are decreasing rapidly as they approach the lining. In the Sudbury Conduit the velocity near its bottom and sides varied 10 per cent. in a distance equal to the diameter of the wheel of the meter.

The accuracy of a meter measurement is probably less affected by this feature than by the others. Its effect can be tested, though less directly than in the other instances, by comparing the discharge over a weir with a point measurement taken in a channel where the flow is steady.

The effect which these different features (variable velocity etc.) have upon the movement of a meter wheel may be better understood from an examination of the manner in which the water strikes the vanes. In doing this only the outer ends of the vanes will be considered, since other portions are acted upon in the same general manner.

Fig. 1, Plate XVIII., is a development of the band of the eight-vane wheel showing by the diagonal lines, *A B*, the position of the ends of the vanes.

If the wheel were stationary, all of the water passing between the points *A* and *C* would strike the vane ;* but if the wheel is revolving, the lower edge, *B*, of the vane, moving in the direction of the revolution, will reach *D*, a point to the left of *B*, while the water is moving the width, *E D* of the band; hence it appears that of all of the particles of water reaching the upper edge of the wheel at any given instant, only those between *A* and *E* will strike the vane, and they strike it in nearly the same way that they would strike a fixed vane with the inclination *A D*.

The line *A D* is drawn at the proper inclination for a current velocity of 2 feet per second; it is practically correct for any velocity exceeding 1.8 feet. This line is represented at the same inclination in all of the figures relating to the same wheel.

In each of the figures on the plate the proportionate number of

---

* In this and succeeding statements the deflection of the current caused by the presence of the meter is disregarded.

SKETCHES SHOWING THE ACTION OF DIFFERENT CURRENTS UPON THE OUTER EDGES OF THE VANES OF THE CURRENT METER.

8 VANE WHEEL. 10 VANE WHEEL.

FIG. 1.

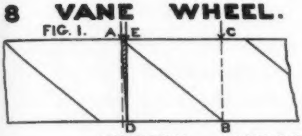
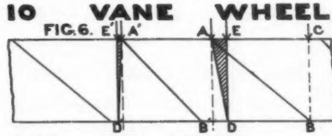


FIG. 6.



UNIFORM VELOCITY 2 FEET PER SECOND.

FIG. 2.

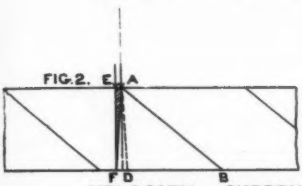
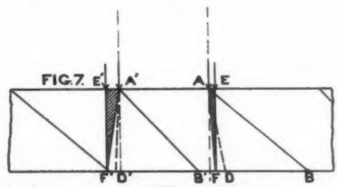


FIG. 7.



VELOCITY SUDDENLY DECREASED 10 PER CENT.

FIG. 3.

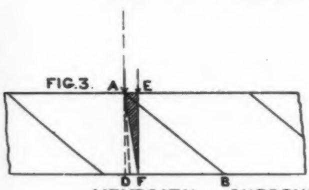
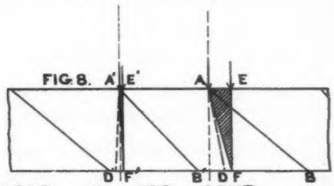


FIG. 8.



VELOCITY SUDDENLY INCREASED 10 PER CENT.

FIG. 4.

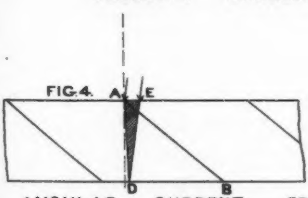
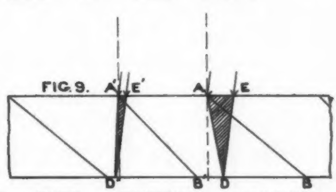


FIG. 9.



ANGULAR CURRENT FROM RIGHT SIDE, BOTTOM VANES.

FIG. 5.

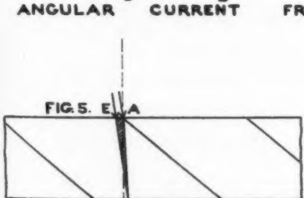
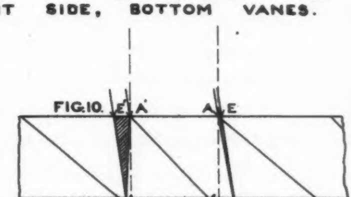


FIG. 10.



ANGULAR CURRENT FROM RIGHT SIDE, TOP VANES.

PLATE XVIII.
TRANS. AM. SOC. CIV. ENGRS.
VOL XII No. CCLXI
STEARNS
ON THE CURRENT METER

particles striking the vanes is indicated by the length $A E$ of the upper side of the shaded triangle.

When E is to the right from A, the pressure on the vane is positive; when E is to the left it is negative.

Fig. 2 represents a case in which the velocity is suddenly decreased from 2.0 to 1.8 feet per second, taken at the instant when the change occurs, and the wheel, owing to its inertia, still revolves at the rate due to its former velocity. It appears in this case, that on account of the increased ratio of the speed of the wheel to the velocity of the water, the lower edge, B, of the vane moves so far that none of the particles of water passing between the points A and C strike it; but, instead, the vane is struck on the other side by some of the water passing to the left of A.

Fig. 3 represents a case where the velocity is suddenly increased from 2.0 to 2.2 feet per second, and consequently more water strikes the vane.

In the former case the speed of the wheel will be retarded, and in the latter it will be accelerated until the inclination $A\ D$, assumed in a steady current, is regained. It is evident that if this inclination was regained in equal times in both cases, changes in velocity would not cause errors in measurement, but it is not probable that this is the case. It is true that the decrease* in the number of particles striking the vane in one case is nearly equal to the increase in the other; but in the former case these particles strike the vanes at a much smaller angle, indicating that the retardation will be accomplished less rapidly than the acceleration, which will cause a meter measurement of variable velocity to be in excess of the truth. The amount of this excess will depend largely upon the rapidity with which the meter responds to changes in the velocity of the water. If it responds quickly, the error may not be so great as to affect a measurement for practical purposes.

When water strikes the meter at an angle with its axis, the band of the wheel on the side from which the water comes intercepts some of it, which would otherwise strike the vanes. Portions of the frame of an instrument constructed like meter No. 2 may act in the same way.

It is evident that intercepting the water will diminish the meter measurement.

In addition to the effect just referred to, angular velocity causes different pressures on the different vanes. This action is illustrated by

* In estimating the decrease in the number of particles, those acting negatively are added to the number withdrawn from acting positively.

Figs. 4 and 5 ; Fig. 4 showing one of the vanes which has greater pressure on account of the inclination of the current, and Fig. 5 showing an opposite vane where the pressure is negative, owing to the same inclination. It seems probable that the effect of these variable pressures will be to increase the meter measurement ; consequently the effect of angular velocity, as a whole, may be either to decrease or increase the measurement, the preponderating influence depending chiefly upon the design of the instrument.

The third case, that of unequal velocity at the two sides of the wheel, is represented by Figs. 2 and 3, already used to illustrate the case of variable velocity ; Fig. 2 showing a vane on the side where the velocity is least, and Fig. 3 a vane on the opposite side.

Near the sides of the Sudbury Conduit, the difference in the velocities at opposite sides of the wheel was about half of the amount represented by the figures, that is, the vane nearest the brick-work had practically no pressure upon it, while the vane on the other side was struck by the water at double the usual angle.

The figures on the right-hand side of the plate represent the ten-vane wheel under the same conditions that the eight-vane wheel is represented by the figures on the left.

Fig. 6 shows that, with the wheel having vanes of unequal pitch, there is, even in a uniform current, a negative pressure on one set of vanes. This form of wheel was constructed because it was thought that the speed of a wheel, governed by the difference between positive and negative pressures, would respond more quickly to variations in the velocity of a current than one where the speed of the wheel was maintained by a light positive pressure only.

Tests made at the Rating Machine.

1.—*Tests of variable velocity.*

These tests were made by moving the meter along the course of the rating machine at very irregular rates. The number of revolutions were noted and compared with the number obtained when rating with the same mean velocity and uniform movement.

The results obtained are shown by Table I.

TABLE I.

EXPERIMENTS ON VARIABLE VELOCITY, MADE AT THE RATING MACHINE IN THE SUDBURY CONDUIT, JANUARY 27TH, 1879.

1 Number of the Experiment.	2 Numbers showing the order in which Experiments were made.	3 Mean Velocity in Feet per Second.	4 Revolutions of the Wheel per Foot, advance with Irregular Movement.	5 Revolutions of the Wheel per Foot, advance when rated in the usual manner.	6 Proportional Differences between Revolutions in Columns 4 and 5: Column 5 being the Standard.
		TEN-VANE WHEEL.			
1...	6	0.986	1.086	1.034	+0.050
2 ..	5	1.108	1.090	1.044	+0.044
3....	3	1.562	1.076	1.064	+0.011
4....	1	1.567	1.061	1.064	—0.003
5....	7	1.592	1.125	1.064	+0.057
6...	2	1.773	1.065	1.069	–0.004
7....	4	3.650	1.063	1.059	+0.004
		EIGHT-VANE WHEEL.			
8....	11	0.850	1.327	1.172	+0.132
9....	8	2.110	1.279	1.237	+0.034
10....	9	2.202	1.291	1.237	+0.044
11...	10	2.660	1.295	1.237	+0.047

The experiments show very conclusively that the irregular movement gives the greater number of revolutions; two experiments, only, showing a small difference in the other direction.

Owing to the fact that the motion of the meter was not equally irregular in all of the experiments, the quantities in column 6 are variable; they indicate, however, smaller differences with the ten-vane than with the eight-vane wheel, and with high velocities than with low ones. The order in which they were made may also have some importance, as the movement in the earlier ones was generally less irregular than it was in those made afterwards.

2.—*Tests of angular velocity.*

In these tests the meter was rated when its axis was at various angles with the track of the rating machine. The observations are given in Table II.

The proportional differences in column 9 are obtained by a comparison between columns 7 and 8, the quantities in column 7 being used in preference to those in column 5, because they correspond more nearly to the cases which usually occur in practice, *i. e.*, to cases in which only the velocity in the direction of the axis is required.

Experiments 1 and 5, in which the angle is 7° 48′, show as the effect of angular velocity an increase in the number of revolutions of about one-half of one per cent. Experiments 2 and 6, with an angle of 10° 48′, show a decrease in the number of revolutions of 1.5 and 2.8 per cent. respectively.

These four experiments indicate that in ordinary measurements a considerable angle between the axis of the meter and the current will not cause an important error, a result of great practical importance.

The remaining experiments, with angles of 24° and 41°, show a much larger decrease, averaging nearly 10 per cent.

These tests of variable and angular velocity were made long before any comprehensive experiments for ascertaining the accuracy of meter measurements were contemplated; consequently they are less complete than they otherwise would have been.

Tests made by Comparing Current-Meter and Weir Measurements.

The measurements were made at a weir 19 feet long in the Farm Pond Gate-house at the head of the Sudbury Conduit. The discharge was computed by a formula deduced from experiments made at this weir. A description of these experiments is given in a paper already published by the Society.*

The water for the experiments was drawn directly from Farm Pond, 165 acres in extent. The flow into the pond was controlled by gates, and, during the experiment, it was made equal to the outflow, thereby keeping the height of the water constant, or nearly so. An observer at the weir read the hook-gauges frequently, and as soon as any change in the depth on the weir was noticed, the openings of the gates which

---

* Transactions, Feb., 1883, p. 61, *et seq.*

TABLE II.

EXPERIMENTS ON ANGULAR VELOCITY, MADE AT THE RATING MACHINE IN THE SUDBURY CONDUIT, JANUARY 27TH, 1879.

1 Number of the Experiment.	2 Wheel used with Meter.	3 Angle between the Axis of the Meter and the Track.	4 Actual Velocity of the Meter.	5 Revolutions per Foot moved in the direction of the Track.	6 Forward Velocity of the Meter.	7 Revolutions per Foot moved in the direction of the Axis.	8 Revolutions per Foot advance with Ordinary Rating, corresponding to Velocities in Column 6.	9 Proportional Differences between Revolutions in Columns 7 and 8; Column 8 being the Standard.
			Feet per second.		Feet per second.			
1....	8-vane.	7° 48′	2.024	1.231	2.006	1.242	1.236	+0.005
2....	"	10° 48′	2.026	1.195	1.989	1.217	1.236	—0.015
3....	"	24° 14′	2.016	1.027	1.838	1.126	1.233	—0.087
4....	"	40° 58′	2.016	0.823	1.522	1.090	1.223	—0.109
5....	10-vane.	7° 48′	2 024	1.066	2.006	1.076	1.070	+0.006
6....	"	10° 48′	2.020	1.022	1.984	1.040	1.070	—0.028
7....	"	24° 14′	1.910	0.882	1.742	0.967	1.068	—0.095
8....	"	40° 58′	1.683	0.728	1.271	0.965	1.053	—0 084

NOTE.—With but few exceptions, each experiment is an average of two closely agreeing observations.

admitted the water were changed until the standard depth was re-established. By this means the flow in the conduit was kept practically constant.

The current-meter measurements were taken at a man-hole 6 000 feet below the gate-house. The arrangement of the apparatus at this place is shown on Plate XIX.* *B* is a slotted piece of wood at the top of the man-hole through which the rod of the meter passed freely in a longitudinal direction, while its side movement was protected. At *A* a handle carrying a small wheel was attached to the rod parallel with the axis of the meter. The small wheel rested on a track *a*, *a*, *a*, made of thin boards sawed to the proper curves and spaced and numbered to correspond with numerous small areas of equal size into which the cross-section of the conduit was divided.

Point-measurements were made by taking the velocity with the meter in each of these areas.

The velocities obtained by five experiments with varying depths of water are shown on Plate XX.† The most interesting feature of the diagrams is the distribution of velocities in different parts of the channel, a subject to be referred to later. The plate is introduced here to show the regularity of current-meter observations having a duration of but thirty seconds each.

The range of the conditions covered by the experiments will now be given:

The depths varied from 1.5 to 4.5 feet, corresponding with each of the horizontal lines shown on Plate XIX., except the top one.

The rate of integrating varied from one-tenth of a foot to one foot per second, or from about 3 per cent. to about 58 per cent. of the velocity of the current.

The velocities varied from 1.71 to 2.93 feet per second.

The motion of the current varied from the very regular motion due to a flow through more than a mile of brick-lined channel, straight for about 3 700 feet from the point of observation, to the very irregular flow caused by two wide boards, placed vertically in the water about 15 feet above the current-meter section.

---

* This plate is reproduced from a report of the work done on the construction of the works for supplying Boston with water from Sudbury River, by A. Fteley, Resident Engineer in charge, p. 95.

† Reproduced from page 100 of report mentioned in foot-note above.

CURRENT METER APPARATUS
at gauging manhole.

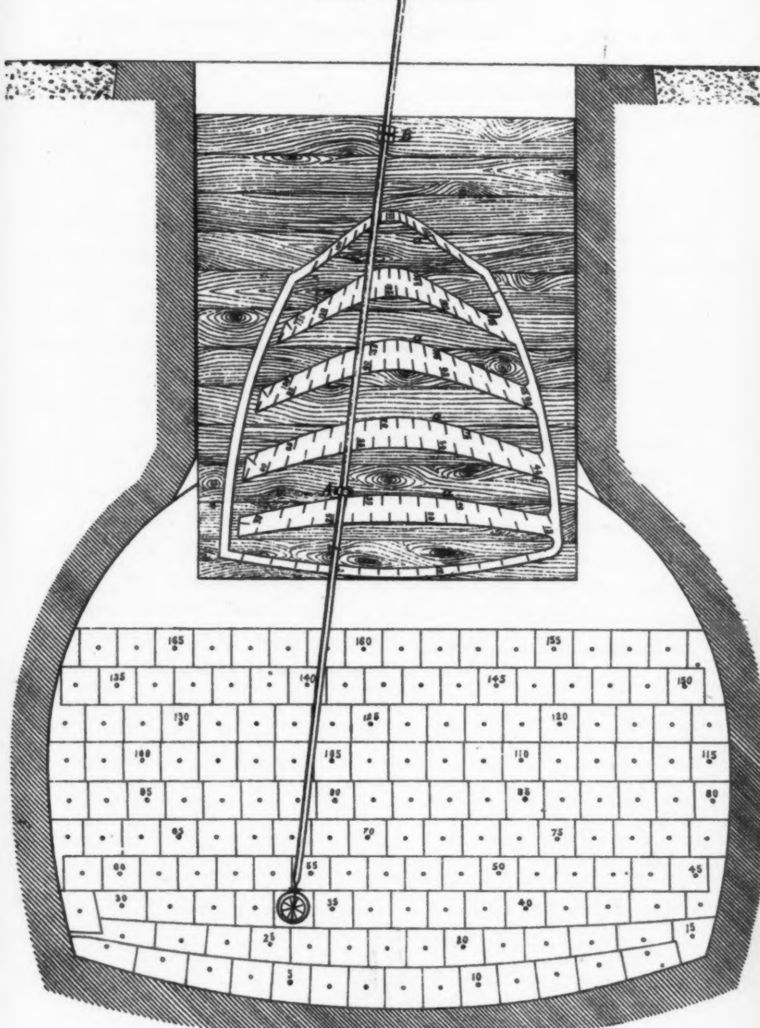


PLATE XIX
TRANS. AM. SOC. CIV. ENGRS.
VOL XII Nº CCLXI
STEARNS
ON THE CURRENT METER

During an experiment frequent measurements of the height of the surface of the water were taken with a point-gauge at the side of the man-hole.

The general features and the results of all of the experiments are give in Table III.

EXPLANATION OF TABLE III.

Column 1.—*Number and conditions of the series.* The experiments are grouped in series, in each of which certain conditions are constant, these conditions being given in this column.

Column 2.—*Number of the experiment.* All measurements made under identical conditions have been combined and are given in the table as one experiment. The number of measurements thus combined is given in column 3.

Column 5.—*Ratio of lateral motion of meter to velocity of current.* This ratio is the tangent of the angle which the impinging current makes with the axis of the meter.

Column 7.—*Percentage of variation of current-meter from weir measurement.* The quantities in this column are the result of a comparison between the volumes flowing as determined by current-meter and by weir measurement. None of the exact data upon which this comparison is based is given in the table, as it is not thought to have sufficient interest. All calculations were checked.

TABLE III.

Comparison of Current-Meter and Weir Measurements made in the Sudbury Conduit, October 27th to November 12th, 1879.

1 Number and Conditions of the Series.	2 Number of the Experiment.	3 Number of Comparisons included in the Experiment.	4 Depth in the Centre of the Conduit.	5 Ratio of Lateral Motion of Meter to Velocity of Current.	6 Mean Velocity of the Current.	7 Percentage of Variation of Current-Meter from Weir Measurement.
			Feet.		Ft. per Sec.	
Series I.	1	1	1.5	0	1.83	+1.2
Point-measurement,	2	2	2.0	0	2.13	0.0
Regular current,	3	1	3.0	0	2.56	+0.1
8-vane wheel,	4	1	4.0	0	2.83	+0.1
Ordinary inclination.	5	1	4.5	0	2.93	—0.4
Series II. Point-measurement, Regular current, 8-vane wheel, Low inclination.	6	1	3.0	0	1.71	—0.2
Series III.	7	3	1.5	0.055	1.83	+0.8
Rate of integrating 0.10 ft. per sec.,	8	3	2.0	0.047	2.13	+0.1
Regular current,	9	8	2.5	0.042	2.37	—0.6
8-vane wheel,	10	3	3.0	0.039	2.56	—0.2
Ordinary inclination.	11	6	3.5	0.037	2.71	—0.1
	12	4	4.0	0.035	2.83	—0.5
	13	4	4.5	0.034	2.93	—0.8
Series IV. Rate of integrating 0.10 ft. per sec., Regular current, 10-vane wheel, Ordinary inclination.	14	4	2.5	0.042	2.37	+0.2

TABLE III.—(*Continued.*)

1 Number and Conditions of the Series.	2 Number of the Experiment.	3 Number of Comparisons included in the Experiment.	4 Depth in the Centre of the Conduit.	5 Ratio of Lateral Motion of Meter to Velocity of Current.	6 Mean Velocity of the Current.	7 Percentage of Variation of Current-Meter from Weir Measurement.
Series V.			Feet.		Ft. per Sec.	
Rate of integrating 0.50 ft. per sec.,						
Regular current,	15	16	2.5	0.211	2.37	—3.6
8-vane wheel,	16	15	3.5	0.185	2.71	—1.8
Ordinary inclination.						
Series VI.						
Rate of integrating 1.00 ft. per sec.,						
Regular current,	17	20	3.5	0.369	2.71	—6.5
8-vane wheel,						
Ordinary inclination.						
Series VII.						
Rate of integrating 0 10 ft. per sec.,						
Regular current,	18	3	3.0	0.058	1.71	—1.0
8-vane wheel,						
Low inclination.						
Series VIII.						
Rate of integrating 0.50 ft. per sec.,						
Regular current,	19	4	3.0	0.292	1.71	—4.5
8-vane wheel,						
ow inclination.						
Series IX.						
Rate of integrating 1.00 ft. per sec.,						
Regular current,	20	7	3.0	0.585	1.71	—9.4
8-vane wheel,						
Low inclination.						

TABLE III.—(*Continued.*)

1 Number and Conditions of the Series.	2 Number of the Experiment.	3 Number of Comparisons included in the Experiment.	4 Depth in the Centre of the Conduit.	5 Ratio of Lateral Motion of Meter to Velocity of Current.	6 Mean Velocity of the Current.	7 Percentage of Variation of Current-Meter from Weir Measurement.
			Feet.		Ft. per Sec.	
Series X. Rate of integrating 0.10 ft. per sec., Irregular current, 8-vane wheel, Ordinary inclination.	21	4	2.5	0.042	2.37	—1.1
Series XI. Rate of integrating 0.10 ft. per sec., Irregular current, 10-vane wheel, Ordinary inclination.	22	3	2.5	0.042	2.37	—0.8
Series XII. Rate of integrating 0.20 ft. per sec., Irregular current, 8-vane wheel, Ordinary inclination.	23	2	2 5	0.084	2.37	—2.3
Series XIII. Rate of integrating 0.50 ft. per sec., Irregular current, 8-vane wheel, Ordinary inclination.	24	6	2.5	0.211	2.37	—3.4
Series XIV. Rate of integrating 0.50 ft. per sec., Irregular current, 10-vane wheel, Ordinary inclination.	25	4	2.5	0.211	2.37	—2.3

TABLE III.—(*Continued.*)

1 Number and Conditions of the Series.	2 Number of the Experiment.	3 Number of Comparisons included in the Experiment.	4 Depth in the Centre of the Conduit.	5 Ratio of Lateral Motion of Meter to Velocity of Current.	6 Mean Velocity of the Current.	7 Percentage of Variation of Current-Meter from Weir Measurement.
Series XV.			Feet.		Ft. per Sec.	
Rate of integrating 1.00 ft. per sec., Irregular current, 8-vane wheel, Ordinary inclination.	26	4	2.5	0.422	2.37	—6.5
Series XVI.						
Rate of integrating 1.00 ft. per sec., Irregular current, 10-vane wheel, Ordinary inclination.	27	4	2.5	0.422	2.37	—5.6

Deductions from the Experiments.

1.—*Comparisons under favorable conditions.*

(*a.*) *Point-measurement.*—This kind of measurement, in a regular current, reproduces more nearly than any other the conditions which exist while the instrument is being rated; consequently it should give the best results.

Series I. and II. represent this case; and they show but small differences between the meter and the weir measurements, as may be seen by reference to column 7. The largest variation occurs in experiment 1, in which the meter measurement is 1.2 per cent. in excess. In the remaining experiments the largest variation is $\frac{4}{10}$ of one per cent. It may be said of these experiments, as a whole, that they do not indicate any definite variation of the meter measurement from the truth in either direction.

(*b.*) *Integrating at a slow rate—regular current.*—In this case the conditions are in a slight degree less favorable than in the one last considered. It is represented by series III., IV. and VII. The differences do not in any experiment exceed one per cent., and their average indicates that the meter measurement is about one-fifth of one per cent. too small.

2.—*Comparisons under unfavorable conditions.*

(*a.*) *Irregular velocity.*—The effect of irregular velocity, if it has any effect, can be seen by comparing the experiments in which the degree of irregularity is the only important variable. Four comparisons of this kind can be made, and they are given below with the percentage that the measurement in the irregular current varies from that in the regular one.

Experiment	9	and Experiment	21, $\frac{1}{2}$ of one per cent. smaller.
"	14	"	22, one per cent. smaller.
"	15	"	24, $\frac{2}{10}$ of one per cent. larger.
"	17	"	26, the results agree.

These comparisons, as a whole, tend to show that smaller results are obtained with the irregular current; but the differences are too small to prove any general law.

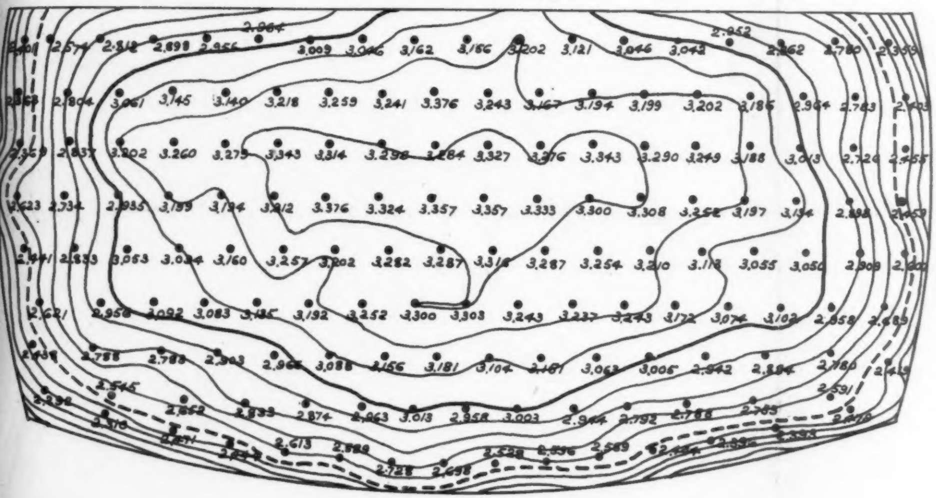
The writer would prefer to consider the experiments as evidence that when other conditions are favorable an irregular current will not prevent an accurate measurement.

PLATE XX.
TRANS. AM. SOC. CIV. ENGRS.
VOL XII No. CCLXI
STEARNS
ON THE CURRENT METER

Diagrams, showing distribution of velocities, and curves of equal velocities in Sudbury River Conduit, [station 59].

Scale of Feet.

0 1 2 3 4



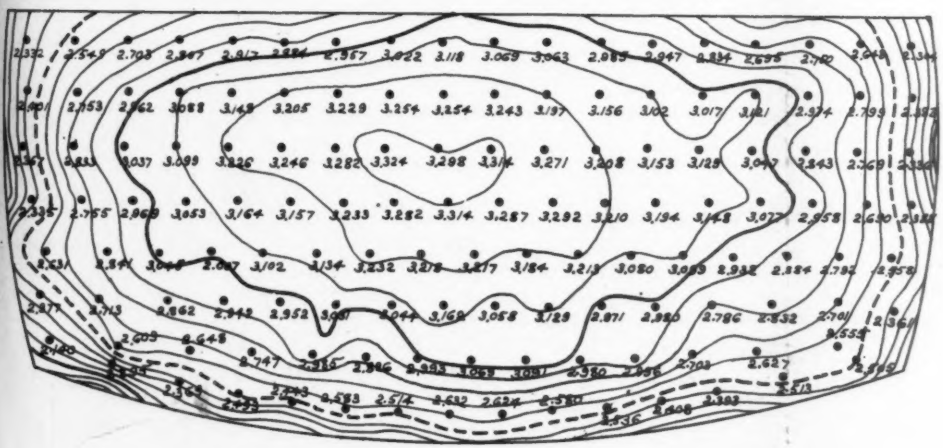
Mean Velocity 2.973

Maximum Vel. {Average of the largest 3.} 3.370

Ratio of mean to max. 88.2%

Depth 4.539

Quantity in cubic ft. per sec. ... 111.470



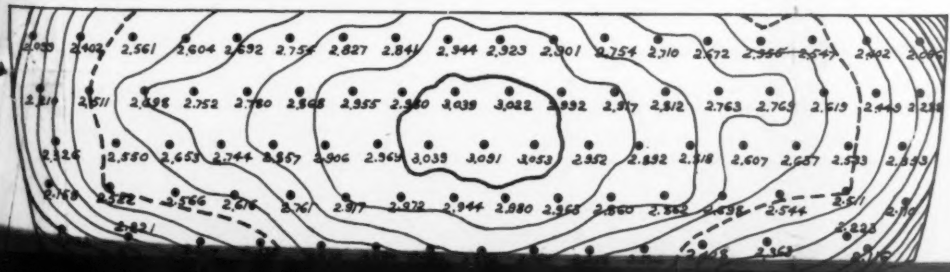
Mean Velocity 2.896

Maximum Vel. {Average of the largest 3.} 3.317

Ratio of mean to max. 87.3%

Depth 4.007

Quantity in cubic ft. per sec. 94.720



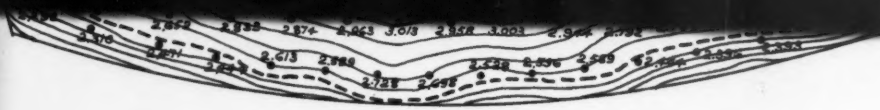
Mean Velocity 2.620

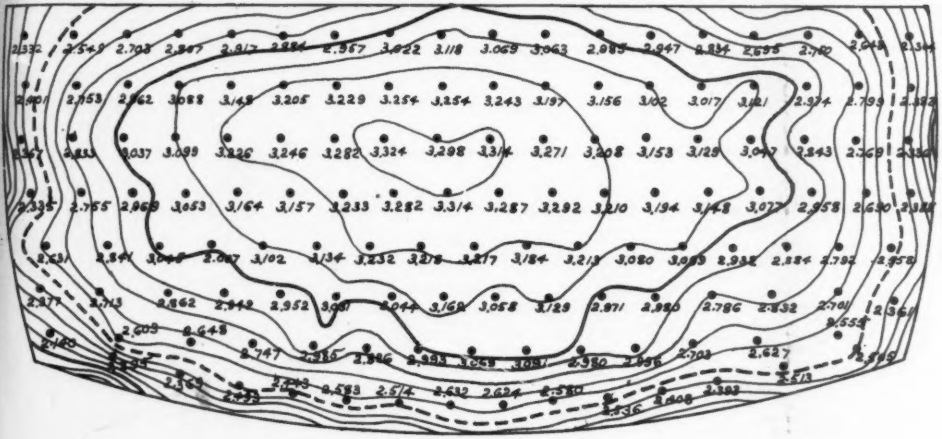
Maximum Vel. {Average of the largest 3.} 3.061

Ratio of mean to max. 85.6%

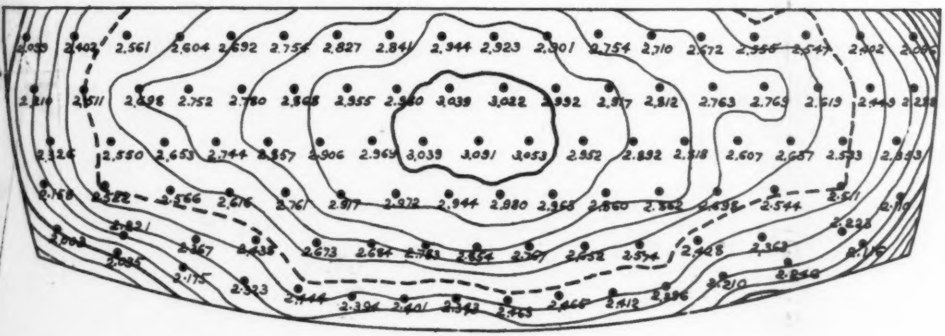
Depth 3.002

Quantity in cubic ft. per sec. 62.430

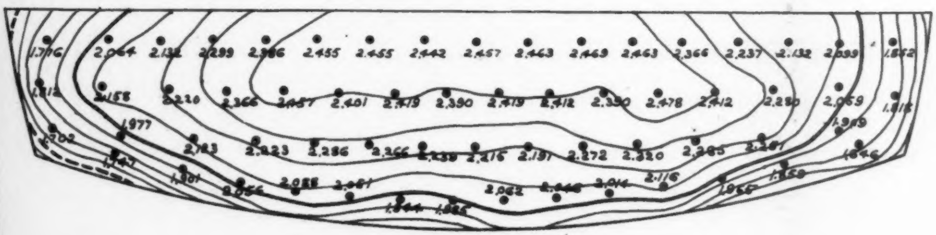




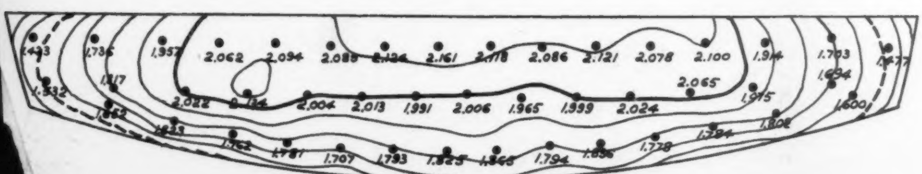
Mean Velocity 2.896
Maximum Vel. {Average of the largest 3.} 3.317
Ratio of mean to max. 87.3%
Depth 4.007
Quantity in cubic ft. per sec. 94.720



Mean Velocity 2.620
Maximum Vel. {Average of the largest 3.} 3.061
Ratio of mean to max. 85.6%
Depth 3.002
Quantity in cubic ft. per sec. 62.430



Mean Velocity 2.180
Maximum Vel. {Average of the largest 3} 2.470
Ratio of mean to max. 88.3%
Depth 2.026
Quantity in cubic ft. per sec. 33.408



Mean Velocity 1.897
Maximum Vel. {Average of the largest 3} 2.140
Ratio of mean to max. 88.6%
Depth 1.508
Quantity in cubic ft. per sec. 20.158

(*b.*) *Integrating at a rapid rate.*—The effect of integrating too rapidly is to diminish the meter measurement. To show how marked this feature is, all of the experiments in which the rate of integrating exceeds one-tenth of a foot per second are collected below. The ratios from column 5, which are the proper measures of the rate of integrating, and also the differences from column 7, are given.

Number of the Experiment.	Ratio of Lateral Motion of Meter to Velocity of Current.	Percentage of Difference of Current-meter from Weir Measurement.
20	0.585	—9.4
26	0.422	—6.5
27	0.422	—5.6
17	0.369	—6.5
19	0.292	—4.5
24	0.211	—3.4
25	0.211	—2.3
15	0.211	—3.6
16	0.185	—1.8
23	0.084	—2.3

It will be seen that the differences are negative in every case, reaching in the extreme instance 9.4 per cent.

The most rapid rate of integrating admissible when accurate results are required, is, from the nature of the case, rather indefinite. The experiments indicate that a rate not exceeding five per cent. of the velocity of the current will give good results.

3.—*Comparison of wheels.*

Four cases occur among the experiments in which the wheel used with the meter is the only variable. The ten-vane wheel gives in every case the result nearest the truth; and it gives a measurement of volume larger than that obtained with the eight-vane wheel by an average of eight-tenths of one per cent.

The differences in the results obtained with the two wheels are not

so large that they may not be attributed to errors incidental to the experiments.

4.—*Effect of inclination, i. e., of velocity.*

In experiments 3 and 6—the only two in which velocity is the only variable—the differences in column 7 are respectively + 0.1 and — 0.2 per cent.; indicating, as might be expected, that there is no appreciable difference due to this cause.

5.—*Effect of depth.*

Near the bottom and sides of a channel there is a thin layer of slow-moving water which the current-meter does not reach; hence the mean of the measured velocities is slightly in excess of the mean velocity of the whole mass. This fact tends to make the meter measurement too large, and its effect will be proportionally greater with smaller depths.

Experiments 1 and 7, in which the depth is but 1.5 feet, show results, respectively, 1.2 and 0.8 per cent. too large. A portion of this excess may be due to the cause just referred to.

Notes upon the Accuracy of the Experiments.

In experimenting there is always a possibility that some nearly constant error may affect all of the experiments to an important extent; therefore it is well to consider the various circumstances of the experiments in order to judge of the trustworthiness of the results.

The volume passing the weir was, as has already been stated, calculated by a formula deduced from experiments in which the water discharged over the weir was measured in a basin below it. This formula varies but two-thirds of one per cent. from a formula deduced from Mr. Francis' experiments; so that it seems beyond question that the weir measurement was not far from the truth. The weir did not leak, and the quantity of water entering the conduit by filtration between the points of observation was known to be unimportant.

The stop-watch used was probably correct within one-tenth, or certainly within one-fifth of one per cent. When a point-measurement was being taken the watch was allowed to run continuously in a position where it could be seen by the person operating the current-meter. The duration of the measurement at each point was 30 seconds; consequently an error of three-tenths of a second affects the result one per cent. It is quite possible in *these* experiments that the personal error of the

observer in connecting and disconnecting the recording wheels at the exact moment may have occasioned an error of a fraction of one per cent.

The rating of the meter described on page 305 *et seq.* was very accurate, but it was done in January, when the instrument was new, and the experiments were made in the following October and November, the meter having been used in the meantime. In July a partial rating was made by one of Mr. Francis' assistants at the rating machine of the Locks and Canals Company at Lowell, Mass. This rating consisted of ten trials with the ten-vane wheel, and eight trials with the eight-vane wheel. These trials were made with velocities of about 1.5 and 2.5 feet per second, and they gave quite regularly a larger number of revolutions per foot advance than the original rating. The revolutions of the eight-vane wheel increased 1.6 per cent.; of the ten-vane wheel 0.6 per cent.

The meter had never been injured, nor had the form of its vanes altered perceptibly, and the only reason which suggested itself to account for the change in the rate was, that the friction of the axis in its bearings might have been greater when the instrument was new than it was after the parts in contact had been worn smooth by use. This explanation of the difference in rate is not very satisfactory ; yet the fact that eighteen trials showed, with but one exception, an increased number of revolutions is deemed a sufficient reason for using the later rating.

This was accomplished by applying the percentages of increase, already given, to the original rating. It is to be regretted that no opportunity occurred for rating the meter at the time when the experiments were made, so that the accuracy of the rating used might be undoubted.

Aside from what has already been stated, no cause of error is known to have existed which would have been more liable to affect the results in one direction than in the other.

The conclusion drawn from the experiments as a whole is, that the current-meter will give results accurate within one per cent., either by point or by integrated measurements, provided, in the latter case, that the rate of integrating does not exceed five per cent. of the velocity of the current. Even if it is admitted that nearly all of the errors, which have been referred to as possible, exist, the above statement will still be correct if its limit of accuracy is modified to one per cent. below and two per cent. above the truth. These percentages are still within the limits

of what is now termed accuracy in the measurement of velocities of water.

There is one other evidence that the meter measurements are not, as a rule, far from the truth in either direction. The differences between the conditions of rating and of measuring in a regular current have been shown, by theoretical considerations already given in this paper, to be much smaller than the differences between the conditions of measurements taken in regular and irregular currents. The experiments show that the degree of irregularity has very little effect on the results, from which it may be inferred that the smaller differences between the conditions of rating and of measuring in a regular current will not affect the accuracy of the results appreciably.

Miscellaneous Notes about the Current-Meter.

In ordinary practice a point measurement is seldom taken, on account of the time and labor involved. In taking integrated measurements it has not been found necessary to resort to mechanical methods for securing uniformity of movement of the meter, nor for holding the axis of the meter parallel with the axis of the current. The process of taking a measurement is generally as follows : The width of the channel is first divided into equal parts, and the divisions are marked plainly on a bridge or plank over the stream.

The meter, at the beginning of a measurement, is placed at the side of the channel just below the surface. It is here that the recording wheels are thrown into gear and the movement of the meter is begun, first down to the bottom, then up to the surface, then down again, and so on.

These downward and upward movements are combined with a continuous side movement towards the opposite side of the channel, so timed that the meter reaches the bottom vertically under the first division mark ; the surface under the second one ; the bottom under the third, and so on until the opposite side is reached. In a rectangular channel each trip of the meter between the surface and the bottom should have the same duration. In an irregular channel the duration of each upward or downward trip should be proportional to its length, and to make it so it is necessary to prepare in advance a table giving the times at which it should reach each point where its course is to be changed, these times to be called by an assistant.

Uniformity of movement may be secured in another way, by marking the handle of the meter plainly every foot or half foot, and by observing that these marks disappear below and appear above the surface of the water after equal intervals of time.

The time required for a measurement of this kind is but a few minutes, and the office work need take but little longer.

Successive measurements taken in the manner described agree very closely, even in channels where the motions of the water are very variable.

It has frequently been observed that a leaf catching on one of the vanes of the larger meter (meter No. 1) did not affect the results appreciably.

Several instruments of the pattern of meter No. 2 have since been made with two registers, one the ordinary register attached to the instrument, and the other an electric register, recording above water each revolution.

It is evident that this meter, being attached to a rigid handle, is not suitable for use in deep water. To adapt it to such use would require some additional apparatus of a kind depending upon the method employed to control the position of the meter. Even a brief consideration of the different methods suggested would require considerable space, and therefore will be omitted.

For information on the subject the reader is referred to the following works:

Report of the Surveys and Examinations of the Connecticut River, by Gen. T. G. Ellis; Appendix B 14 of the Annual Report of the Chief of Engineers for 1878, p. 61: On the Flow of Water in Rivers and Canals, by D. Farrand Henry; Journal of the Franklin Institute, 1871, Vol. LXII. p. 171: Hydraulics of Great Rivers, by J. J. Révy: The Current-Meter of Prof. A. R. Harlacher, by Richard Blum; Minutes of Proceedings, Inst. C. E., Vol. LXVII., p. 358, also Engineering News, 1882, p. 141: The Measurement of Velocity for Engineering Purposes, by H. S. H. Shaw; Minutes of Proceedings, Inst. C. E., Vol. LXIX.: On a Current-Meter, etc., by B. T. Moore; Minutes of Proceedings, Inst. C. E., Vol. XLV., p. 220.

There seems to be but one thing to prevent the general use of current-meters by engineers having occasion to measure the flow of water; this is, that a meter when purchased has no practical value until it is

rated. The erection of a rating apparatus similar to that described in this paper is neither very difficult nor expensive, provided a proper location can be had, but such a location is not, as a rule, within the control of engineers.

Until instruments can be bought already rated, some simpler method of obtaining the rate is much to be desired. It is true that meters can be constructed so nearly alike that the rate of any two will be quite nearly the same, but until many have been tested and the rates have been found to agree, measurements taken with instruments that have not been rated will be classed as doubtful.

The various methods of rating a meter appear to be : to move the meter a given distance through still water ; to measure with the meter the flow in a channel where a known volume is passing; and to compare measurements taken with two meters, one having a known rate. Of these three methods the first is the more direct, and seems to be open to fewer objections than the others. The difficulties in its use would be very much diminished if it should be found by future experiment that a good rating can be made in a very small channel. It seems quite probable that results sufficiently accurate for ordinary practical purposes might be obtained in a trough from 30 to 50 feet long and from 1 to 2 square feet in section.

A REASON WHY THE MAXIMUM VELOCITY OF WATER FLOWING IN OPEN CHANNELS IS BELOW THE SURFACE.

This subject, which appears to have interested hydraulic engineers very much, has already been before the Society; the Transactions for May, 1878, containing a paper by Mr. J. B. Francis, Past President Am. Soc. C. E., "On the Cause of the Maximum Velocity of Water Flowing in Open Channels being Below the Surface." This paper was discussed by Messrs. Theodore G. Ellis, Charles E. Emery, Clemens Herschel, De Volson Wood,* and John T. Fanning.

In all, three theories were advanced and many facts deduced from observations were noted.

At the time Mr. Francis' paper was published, the writer held substantially the same views that he now proposes to advance, but they were not, at that time, based upon sufficient data to warrant their presentation.

Theory.

Let us first suppose the case of a single obstacle projecting from the lining of a channel. The current approaching this obstacle loses some of its velocity just before reaching it, and thereby causes an excess of head in a small pyramid of water just above the projection.

This excess of head, in turn, causes a transverse flow of the water in all directions; but the *strongest* transverse flow will be in the direction of the least resistance, which is, as a rule, vertically towards the surface.

The irregularities upon the surfaces of even the smoothest channel linings met with in practice are very large in comparison with the size of the particles of water striking them, and they may be considered as obstacles present in all parts of the lining, each tending to produce an upward flow, as above indicated.

Although the *tendency* to upward flow is general, yet since it cannot *occur* without a corresponding downward flow to replace the water which rises, it follows that it will take place only in those portions of the width of the channel where the obstacles producing it are the more frequent and nearer the surface, *i. e.*, generally at or near the sides.

* The discussion by Prof. Wood, as given in the Transactions of May, 1878, is supplemented by a paper on the same subject in the Transactions of July, 1879.

It is, therefore, the theory that there is at the sides of channels an upward flow,* due to the cause already described, which carries with it the slow-moving water always found in the immediate vicinity of channel linings, and that this water, reaching the surface, flows towards the middle of the channel, retarding by its slower movement the velocity of the surface layers, thereby causing the maximum velocity to be, in most cases, below the surface.

It must not be inferred from what has just been stated, that the writer believes there is a continuous flow in the directions indicated, since it is well known that the motions of water are very irregular, particularly in channels with rough linings or variable sections, and that masses of water find their way from the bottom to the surface in the middle of the channel as well as elsewhere. The idea which he wishes to convey is, that in most cases the resultants of these irregular movements are in the directions indicated.

If the theory which has been advanced is true, observations should show the following features:

1. An upward flow at the side of a channel.
2. A surface flow towards the centre of a channel.
3. The depression of the maximum velocity should increase with the roughness of the lining.
4. The depression of the maximum velocity should increase as the channel becomes deeper in proportion to its width; since increased depth adds to the number of obstructions at the sides and thereby increases the upward flow, while increased width removes the middle of the channel further from the influence of the inward flow at the surface.
5. The depression of the maximum velocity should be greater in a channel with vertical sides than in one where the sides are inclined, since the ratio of the number of obstructions at the sides to the number at the middle of the channel is greater in the former case than in the latter.
6. If the lining of the sides and bottom are not of the same character, the greater depression of the maximum velocity should occur when the sides have the rougher lining.

---

* The upward flow at the sides of channels and its effect in depressing the maximum velocity was first brought to my attention about six years since by Mr. Hiram F. Mills, Engineer of the Essex Company, Lawrence, Mass., during some conversation about a certain vertical velocity-curve. From some recent correspondence with Mr. Mills, I have learned that at the time this conversation took place he had investigated the subject and had written a paper about it which has not yet been published. In view of this knowledge, I decided not to present the second part of this paper, but changed my decision at his request.

Observations Supporting the Theory.

1.—*Upward flow at the sides of a channel.*

At the current-meter station in the Sudbury Conduit, it was observed that of the many bubbles which floated past none were within about 1 foot of the sides of the conduit. This is evidence that the surface water near the sides came from below, otherwise the bubbles would have been distributed over all parts of the surface.

The feature just noted was also very marked in a straight channel about 6 feet wide paved with rough rubble-stones laid without mortar.

A further test of the theory of upward flow was made by increasing the obstruction at the side until the upward flow was made visible. This was done by placing a 6-inch board vertically in the current at the side of a rectangular channel 19 feet wide. Sawdust was mixed with the water so that its motions might be traced, and it was observed that the water flowed from below along the up-stream face of the board to the surface, where it moved towards the middle of the channel.

2.—*Surface flow towards the centre of a channel.*

The observations already noted as supporting the theory of upward flow are almost equally applicable to inward flow at the surface, and, in addition, may be quoted Major Allan Cunningham's statement,* based chiefly upon his Roorkee Hydraulic Experiments, that "even with artificial straight banks the employment of floats close to the edge is very difficult, in consequence of a prevailing transverse surface-current from the edges, which is so marked that in a float-course only 7½ inches from a straight vertical bank, occasionally one hundred surface floats were run before three were obtained in fair course over a 12½-feet run. This transverse surface-flow is supposed by some to be caused by the reduction of pressure at the centre, consequent on the higher central velocity.† To keep up the water-level at the edge, this surface-flow from the edge clearly involves a sub-surface-flow towards the edges; the experiments showed this indirectly, in that the deeply-immersed double-floats and rods moved without any general bias."

The statement above quoted is based upon extensive experiments and is very conclusive as regards the upward and inward flow of water, though

* Recent Hydraulic Experiments, pp. 25 and 26.

† On the Steady Flow of a Liquid. By Henry Moseley, Canon of Bristol. Philosophical Magazine, Vol. XLII., p. 353; Vol. XLIV., p. 44.

the suggestion as to the cause conflicts with the ideas advanced in this paper.

3.—*Depression of the maximum velocity due to increased roughness of lining.*

This feature is shown plainly in the experiments of Darcy and Bazin;* the most marked instances being seen by comparing the distribution of velocities in rectangular channels lined with pure cement or planks, with that in similar channels lined with planks to which laths had been nailed every 2 inches $\left(\overset{m}{0}.05\right)$; also by comparing semicircular channels lined with pure cement and with gravel.

4.—*The increased depression of the maximum velocity due to increased ratio of depth to width.*

This feature is plainly shown on Plate XX., p. 324, which represents the distribution of velocities in the Sudbury Conduit with different depths of water; it also appeared prominently in the experiments of Darcy and Bazin and is referred to by them.†

The experiments of Révy‡ on the La Plata, taken where the water was 25 feet deep, several miles from the shore, showed the maximum velocity to be at the surface, also that the velocity decreased from the surface to the bottom at a uniform rate. These experiments may be said to indicate that, at a point sufficiently removed from the influence of the sides, any channel having a nearly level bottom will also have the maximum velocity of current at the surface. This cannot, however, be considered more than an indication, since the experiments were few in number, and were made upon only one vertical in a channel affected somewhat by tides.

5.—*The greater depression of the maximum velocity when the sides are vertical than when they are inclined.*

This feature is noticeable in the experiments of Darcy and Bazin when the distribution of velocities in triangular or semicircular channels is compared with the distribution in rectangular channels having the same linings; it is not shown so definitely, however, as the other features already referred to.

---

* Recherches Hydrauliques, Plates XIX., XX. and XXI.

† Recherches Hydrauliques; Text, pp. 233, 234; Plates XVIII.-XXI.

‡ Hydraulics of Great Rivers, by J. J. Révy, Plate II.

In an experiment made in a canal lined with planks, one side being vertical and the other inclined at an angle of 45 degrees, the maximum velocity was not in the middle of the channel, but was nearer the inclined side, indicating a stronger flow of the slow-moving water from the vertical side than from the other. In another canal having a form similar to the one last described, but in which the nearly vertical side was of masonry laid in mortar, the bottom of muddy earth, and the inclined side a paving of rubble-stone, laid dry, for nearly the full height with earth above it, the maximum velocity, instead of being nearer the inclined side, was very near the vertical wall. It appears in this case that the roughness of the inclined side, shown by the drawing* as well as indicated by the description, had a greater effect in increasing the upward flow than its inclination had in decreasing it.

6.—*The increased depression of the maximum velocity when the lining of the sides is rougher than the lining of the bottom.*

No experiments bearing upon this subject could be found, except the one just referred to in which the influence of different linings was combined with the influence of an unsymmetrical section of channel.

Conclusions of other Writers.

The conclusions reached and theories advanced by some writers who have sought to explain why the maximum velocity is below the surface, will be referred to briefly for purposes of comparison.

Mr. Francis has suggested† that it may be due to the slow-moving water at the bottom rising in masses to the surface, and to show that such an action does take place, he gives an account of some experiments which showed that whitewash discharged in the middle of a canal a few inches above its bottom appeared at the surface not very far down stream. He does not think it can be attributed in a large degree to the resistance of the air.

Gen. T. G. Ellis has made the following statement:‡ "It has troubled hydraulic engineers a great deal to know what causes this resistance at the surface, and I will confess that I am unable to solve that problem, although there is some reason, in my opinion, to believe that it is

---

* Recherches Hydrauliques, Plate XXIII.

† Transactions of the Society, May, 1878.

‡ Transactions of the Society, May, 1878, p. 123.

caused by the resistance of the banks and of the bottom near the banks. We find that in very wide and shallow streams the velocity approaches very near the surface, while in deep streams, with steep banks, the thread of greatest velocity is carried lower down. As instances of this, there are the experiments of Mr. Révy, on a section 5 miles wide with a depth of 40 or 50 feet, in which he observes the current and finds the greatest velocity at the surface; and in the experiments of Darcy and Bazin, as published in their works, we find that in rectangular channels we have the greatest velocity nearly in the middle of the section; the retardation at the middle of the surface seems to be communicated in some way from the sides; the water near the sides being so much slower, would seem, being near the surface, to hold it back near the middle. It seems to me that this offers the only plausible solution of the problem. It is found that in very wide rivers we have the greatest velocity near the surface, and in rivers with contracted and steep, perpendicular banks, the thread of greatest velocity is carried down almost to the middle. That fact would seem to verify this theory."

In another place he says: "I think Mr. Francis is undoubtedly right in saying that it is not the effect of wind or the resistance of the air upon the surface of the water that causes the retardation."

Mr. Charles E. Emery has given an explanation,* based upon the assumption that particles of water move in paths that are approximately cycloidal curves.

Prof. DeVolson Wood, premising that a downward flow of particles of water from the surface to the bottom must occur to replace the water rising from the bottom, as demonstrated by the experiments of Mr. Francis, says:† "That gravity acting upon the particles during their descent would accelerate, or at least would tend to accelerate, their motion; and that the action of gravity, combined with the motions impressed by the mutual actions of the particles, might account for the position of the point of the maximum velocity."

Mr. D. Farrand Henry, after a comprehensive review of accessible experiments, states,‡ that the descent of the maximum velocity seems to depend upon the ratio of the depth to the width, increasing with the depth, and upon the character of the bed, increasing somewhat with its

* Transactions of the Society, May, 1878, p. 124.

† On the Flow of Water in Rivers; Transactions of the Society, July, 1879, p. 174.

‡ On the Flow of Water in Rivers and Canals, by D. Farrand Henry; Journal of the Franklin Institute, 1871, Vol. LXII., p. 327.

roughness; also, that the maximum velocity is lower in rectangular than in triangular channels. He also notes a fact which is observable by an inspection of Plate XX., that the lines of equal velocity follow approximately parallel with the bottom and sides until in the vicinity of mid-depth, "when they bend inwards toward the centre, as if forced off from the upper portion of the vertical sides."

Among the experiments of Darcy and Bazin are some* on the flow through a covered rectangular flume running full under a small pressure, and when running half full under the ordinary conditions of an open channel. In the former case the lines of equal velocity followed the form of the section with almost rigid exactness, while in the latter case they show the peculiar irregularities observable in the other open rectangular channels. Referring to these experiments, M. Bazin remarks, that the uniform distribution of velocities in the flume, when filled, is caused by the invariability of the sides, which establishes a kind of solidarity between all parts of the liquid, and opposes all irregular movements and ripples such as are noticed upon the surface of canals. He adds:† "In the flow in the open channel, on the contrary, the absence of resistance upon the upper surface of the current and the want of symmetry and invariability in the section favors the production of all kinds of irregular movements that approach the surface; and it is to this cause, without doubt, that we may attribute in a great part the diminution of velocity in the surface layers." After stating that it cannot be due to the resistance of the air, he concludes: "It is, therefore, in the very nature of the constituent parts and in the interior movements of the current that we must seek the cause of the irregularities which are produced in the upper layers."

The latest observations on this subject which have come to the writer's notice are those of Major Cunningham. As a result of his experiments at Roorkee, he observes:‡ "That neither the actual nor the proportionate depression of the maximum velocity depends much on the depth of water, surface-slope, velocity, or state of wind;" also, "All modern experiment shows that forward velocity decreases with approach to a resisting margin. It appears to the author that the air itself must be looked on as an efficient upper resisting margin in all open channels, and if air be resistant at all, then it is an ever-present cause of retarda-

* Recherches Hydrauliques, Plate XVIII.

† Recherches Hydrauliques, pp. 180–181.

‡ Recent Hydraulic Experiments, p. 18.

tion of forward surface-flow. If it be so even in a small degree, the maximum velocity-line must necessarily be everywhere depressed, and in a rectangular channel this depression would increase towards, and be greatest (but above mid-depth) at the banks, because the resistance of the wet border, namely, sides and tops, would increase towards the banks. These conclusions agree with the results shown in both Bazin's experiments and in the Roorkee hydraulic experiments."

From the quotations which have been given, it will be seen that the opinions held by different writers as to the cause of the depression of the maximum velocity are very diverse, and it may be that the next one who essays to elucidate the subject will place the theory advanced in this paper among those from which he dissents. In reviewing the whole subject, however, the author finds the evidence very strong that an upward flow at the sides and a flow toward the centre at the surface are reasons for a lowering of the position of the maximum velocity.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

CCLXII.

(Vol. XII.—August, 1883.)

DISCUSSION ON THE INCREASED EFFICIENCY OF RAILWAYS FOR THE TRANSPORTATION OF FREIGHT.*

CHARLES DOUGLAS FOX, Cor. M. Am. Soc. C. E. (by letter).—I regret that I am so much occupied with professional engagements at present as to be quite unable to do justice to the important questions brought under review in the paper to which you call my attention.

English railway managers and engineers have long realized the great importance, with a view to economy of working, of a thoroughly substantial "road-bed," and the formation widths on the chief railways are now made 30 feet, both in cuttings and on embankments, for a double line. The greatest care is taken to thoroughly drain this formation in cuttings by the use of deep grips on each side, having earthenware drain pipes laid in them, and filled in with broken stone or other dry material, the water being carefully led away at the mouth of the cutting. The ballast, consisting of broken stone, clean gravel, coarse sand, burnt clay or ashes, is not allowed to be less than 1 foot in thickness below the bottom of the sleepers (or cross-ties); the dimensions for a double line being not less than 22 feet wide at bottom, 27 feet wide at top, by 2 feet thick, well packed under the sleepers, and opened up intermediately for drainage. For lines of constant and heavy traffic, requiring a tolerably frequent renewal of sleepers and rails, the bull-head (a double-headed

* Transactions Am. Soc. C. E., Vol. XI., p. 365, No. CCXLVIII., by William P. Shinn, M. Am. Soc. C. E. (November, 1882); also, Vol. XII., p. 126 (April, 1883); p. 180 (May, 1883), and p. 189 (June, 1883).

rail, having a large top member for wear, and a very small bottom member) is found to be the best section for steel rails, being more readily handled than the Vignoles section, and not requiring reversing, as in the case of double-headed rails, with equal sections in the top and bottom members.

The weight of these rails is 84 pounds per lineal yard, fished with deep fish-plates, or in some cases with ordinary fish-plates resting in a joint chair. The chairs weigh from 40 up to 46 pounds each, and the rails are secured in them by keys of compressed oak, the chairs themselves being fastened to the sleepers by two spikes and two treenails. The sleepers, sometimes creosoted, but often not, are of Baltic redwood, cut from 10-inch by 10-inch by $8\frac{1}{2}$ feet blocks, sawn through the middle, and they are laid about 2 160 to the mile of double line.

The tendency of English railway companies is increasingly to expedite traffic, both in passengers and goods, not by higher rates of speed, but by reducing the number of stoppages, and with a view to this, the number of facing points at stations is reduced to a minimum, and such as cannot be avoided are locked with the signals by a bar which renders it impossible to move the switch whilst a train is passing over it.

The system of interlocking signals and block sections, operated by telegraph, has very much increased the carrying capacity of our railways, whilst minimizing accidents.

The trunk lines are gradually quadruplicating their tracks, in some cases throughout, in others by the insertion of sidings several miles in length, enabling fast trains to overtake and pass by the goods trains without impeding the progress of the latter.

Shunting engines are often worked continuously, but there is, I think, a very general feeling in England in favor of identifying the driver with his engine, and holding him responsible for its efficient working. On some lines the name of the driver is attached to the engine in a conspicuous place. Where water is bad, continuous working naturally tends to increase priming.

The practice of companies differs as to the ownership of wagons, some encouraging, but the majority discouraging the running of rolling stock belonging to private traders.

The accompanying regulations of our Board of Trade, for the construction and working of railways, may be interesting to members who may not have already seen them.

REGULATIONS OF THE ENGLISH BOARD OF TRADE, FOR THE CONSTRUCTION AND WORKING OF RAILWAYS.

A.

DOCUMENTS TO BE SENT TO THE RAILWAY DEPARTMENT, BOARD OF TRADE,

Previously to the Second Notice of the Intention to Open a Railway being given.

I.—A copy of the parliamentary plan and section, with any deviations which may have been made during construction marked thereon in red; and with the corrections in the distances, levels, inclinations, sections of ground, and radii of curves, rendered necessary by such deviations, also marked in red; as well as the positions of the several stations, and the lengths and heights of the platforms; and the widths of cuttings and embankments on each side of the railway.

II.—A table of gradients and level portions, with the positions of the stations distinctly shown.

III.—A table of curves and straight portions.

IV.—A table of cuttings and embankments.

V.—A table of the bridges for roads crossed by the railway.

VI.—A table of the bridges and viaducts over watercourses and valleys.

VII.—A table of all level crossings, public, occupation, private, bridle or foot-way.

VIII.—A table of tunnels.

IX.—A table of aqueducts and of culverts 3 feet or more in diameter.

According to the forms forwarded herewith, observing that the situations of works, &c., should be described in each by reference to the same fixed point; and that it will be convenient if the station nearest to the metropolis, for a main line, or the junction with the main line for a branch railway, be adopted as such point of reference.

X.—A statement affording detailed information under the following heads:

1st. PERMANENT WAY.—Whether the line be double throughout, or partly double and partly single, or single throughout with sidings; the distances from the fixed point adopted in the tables, at which the single portions commence and terminate—or, for a single line, at which the sidings commence and terminate; whether the land has been purchased for an additional line of rails, or whether any other arrangements have been made with a view to adding an additional line at a future period; the width of the line at formation level; the gauge; the width between the lines where double; the description of rails employed, with a diagram section, their length and weight per yard; the description and weight of the chairs, where these are employed; the mode of fixing the chairs and securing the rails; the fastenings adopted for the joints of the rails; the description of sleepers, with their smallest and average scantling and length; their distances from centre to centre if transverse, and if longitudinal the details of any ties by which they are connected; the nature of the ballast, and its depth below the under surface of the sleepers; the description of points adopted; the number and positions of all facing points connected with the main line; and the names of the stations or other places at which engine-turntables are provided.

2d. FENCES.—Description of fencing adopted on each portion of the line, especially the height of the rails, and distance between posts, if post and rail; the height, number of wires, distance between supports, and means of straining, in the case of wire fencing.

3d. DRAINAGE.—General description of the drainage employed; and if on any part of the line it has been attended with peculiar difficulty, a detailed description should be given.

4th. STATIONS.—Their names and their distances, at the commencement and termination, respectively, from the fixed point; the gradients on which they are situated and approached; the length of the platforms and their height above the level of the rails; and the positions of and distances between the home and the distant signals.

5th. WIDTH OF LINE.—The minimum space allowed from a height of 2 feet 6 inches above the rails, between the sides of the widest carriages in use upon the railway and any fixed works, such as pillars and walls at stations, abutments, piers, supports, arches, girders, telegraph posts, sheds, &c., along the line. The minimum section of each tunnel should

be appended, showing within it a section of the widest carriage to be used on the line.

6th. Bridges and Viaducts.—Drawings in detail of all bridges and viaducts, either over or under the railway, accompanied by sufficient information to allow of the probable strength of each being ascertained by calculation, and by sections showing the distances between the girders and the sides of the widest carriages to be used on the line, when the girders are more than 2 feet 6 inches above the level of the rails.

7th. Diagrams of all junction and station arrangements.

XI.—Carriages to be used for the Conveyance of Parliamentary or Cheap Train Passengers under the Act 7 & 8 Vict., c. 85.—The following minimum dimensions should be observed in the construction of these carriages: They should contain 20 cubic feet of space per passenger; the area of the glass windows should afford 60 superficial inches per passenger; they should be provided with proper means of ventilation, and with two lamps at least to each carriage; the seats should be provided with backs, should be 15 inches broad, and should afford 18 inches in width per passenger. Drawings of these carriages, consisting of the three following figures, to a scale of not less than 4 feet to an inch, viz.:

1. An outside elevation, showing the positions of the windows, ventilators and lamps.
2. A transverse section.
3. An inside plan, showing the arrangements of the several seats, with references by letters, specifying the width and length of each seat, and the number of passengers to be accommodated on each; also a memorandum of the size of the windows and ventilators, stating whether they are fixed or constructed to open and close, and the positions of the lamps for lighting the carriages at night.

B.

MEMORANDUM OF IMPORTANT REQUIREMENTS.

1. The requisite apparatus should be provided at the period of inspection for ensuring an adequate interval of space between following trains.

2. Home-signals and distant-signals for each direction should be

supplied at stations and junctions; with extra signals for such sidings as are used either for the arrival or for the departure of trains.

3. The levers of points and signals should be brought close together, into the position most convenient for the person working them, and should be interlocked. The points should be provided with double connecting rods. The levers of the points should be sufficiently long to enable the pointsmen to work them without risk or inconvenience, and should not be placed on the ground between the lines of rails. Any signal which is worked by a wire or rod should be so weighted as to fly to or to remain at "danger" on the fracture of the wire or rod.

4. The levers of points and signals should, as a rule, be brought together under cover upon a properly constructed stage, with glass sides inclosing the apparatus. They should be so arranged that while the signals are at danger the points shall be free to move; that a signalman shall be unable to lower a signal for the approach of a train until after he has set the points in the proper direction for it to pass; that it shall not be possible for him to exhibit at the same moment any two signals that can lead to a collision between two trains; and that after having lowered his signals to allow a train to pass he shall not be able to move his points so as to cause an accident or to admit of a collision between any two trains. The facing points should be provided with apparatus which will ensure the points being in their proper positions before the signals are lowered, and which will prevent the signalman from shifting the points whilst a train is passing them. Every signalman should be able to see the arms and the lamps of the home as well as the distant signals, and the working of the points or of the indicators showing their position, the back lights of the lamps being made as small as possible having regard to efficiency. When the front lights are visible to the signalman in his cabin, no back lights should be provided. The fixed lights in the signal-cabins should be screened off, so as not to be mistakeable during fogs for the signals exhibited to control the running of trains. If, from any unavoidable cause, the arm or lamp of any signal cannot be seen by the signalman, a repeater should be provided in the cabin. Clocks should be placed in conspicuous positions for the use of the signalmen.

5. Facing points should be avoided as far as possible, but when used they should be secured by facing point locks and locking bars; the length of the locking bars should exceed the greatest distance between

the adjacent wheels of passengers' carriages, and the stock rails should have the gauge preserved by gauge ties. When facing points cannot be dispensed with, they should be placed as near as possible to the levers by which they are worked or bolted, and in no instance at a greater distance than 150 yards from those levers. The points should be worked or bolted by rods and not by wires.

6. It being necessary that a uniform system of signals should be adopted on all railways, the semaphore arm should at junctions be on separate posts or on brackets; and at stations when there is more than one arm on one side of a post, they should be made to apply,—the first or upper arm to the line on the left, the second arm to the line next in order from the left, and so on; but in cases where the main or more important line is not the one on the left, separate signal-posts should be provided, or the arms should be on brackets. The distant-signals should be distinguished by notches cut out of the ends of the semaphore arms where such are employed. In no case should a distant-signal arm be placed above a home-signal arm on the same post for trains going in the same direction. In the case of sidings, a low and short arm, distinct from the arm or arms for the passenger lines, may be employed.

7. The junctions between passenger lines and goods and mineral lines and sidings should be protected by home and distant signals. The sidings should be so arranged that the shunting carried on at them shall present the least possible obstruction to the passenger lines. There should be safety points upon each goods and mineral line and siding, with the points closed against the passenger lines and interlocked with the signals. In the case of sidings joining single lines on favorable gradients, where the train staff and ticket system is in use for working the traffic, a key attached to the staff may be used for opening the sidings, and signals may be dispensed with.

8. When a junction is situated near to a passenger station, or is connected with goods or mineral sidings, the platforms and sidings should be so arranged as to prevent, as far as possible, any necessity for shunting over the junction.

9. The junctions of all railways should, in ordinary cases, be formed as double-line junctions.

10. The lines of railway leading to the passenger platforms should be so arranged that the engines, as they arrive and depart from a

station, shall always be in front of the passenger trains ; and that, in the case of double lines or of passing places on single lines, each line shall have its own platform.

11. Platforms should be continuous, and not less than 6 feet wide for stations of small traffic, nor less than 12 feet wide for important stations ; the descent at the ends of the platforms should be by ramps, and not by steps. Pillars or columns for the support of roofs or other fixed works should not be nearer to the edge of the platform than 6 feet. It is considered desirable that the height of the platforms above the rails should not be less than 2 feet 6 inches. The lines should be laid down so as to leave as little space as possible between the edges of the platforms and those of the continuous footboards on the carriages. Shelter should be provided on every platform, and conveniences where necessary.

12. When stations occur on or near a viaduct or bridge under the railway, a parapet or fence on each side should be provided, sufficient to prevent passengers falling from the viaduct or bridge in the dark. Viaducts under the railway should be provided with handrails and with projecting platforms for the protection and escape of the platelayers. Viaducts of timber and iron should be provided with manholes and other facilities for inspection.

13. The steps of staircases approaching stations, and of foot bridges over the lines, and of foot sub-ways, should not be less than 11 inches in the tread nor more than 7 inches in the rise, and all such staircases should be provided with efficient handrails.

14. Clocks should be provided at all stations in positions visible from the line.

15. Turntables for the engines, of sufficient diameter to enable the longest engines and tenders in use on the line to be turned without being uncoupled, should be erected at terminal stations, and at junctions and other places at which the engines require to be turned, except in cases of short single lines not exceeding 15 miles in length, where the stations are not at a greater distance than 3 miles apart, and the railway company is willing to give an undertaking to stop all trains at all stations. Care should be taken to keep all turntables at safe distances from the adjacent lines of rails, so that engines, wagons or carriages when being turned may not foul other lines, or endanger the traffic upon them.

16. No station should be constructed, and no siding should join a

passenger line, on a steeper gradient than 1 in 260, except where it is unavoidable. When the line is double, and the gradient at a station or siding-junction is necessarily steeper, and when danger is to be apprehended from vehicles running back, a catch-siding, with points weighted for the siding, should be provided further down the incline than the passenger platform, siding-junction, or goods yard, to intercept runaway vehicles. Under similar circumstances, when the line is single, in the case, 1st, of a station, a second line should be laid down, a second platform should be constructed, and a catch-siding similarly provided; and in the case, 2d, of a siding-junction, means should be provided for placing the whole train in sidings clear of the main line before any shunting operations are commenced.

17. In a cast-iron bridge the breaking weight of the girders should be not less than three times the permanent load due to the weight of the superstructure, added to six times the greatest moving load that can be brought upon it.

In a wrought-iron or steel bridge the greatest load which can be brought upon it, added to the weight of the superstructure, should not produce a greater strain on any part of the material than 5 tons where wrought-iron is used, or 6½ tons where steel is employed, per square inch.

The engineer responsible for any steel structure should forward to the Board of Trade a certificate to the effect that the steel employed is either cast-steel or steel made by some process of fusion subsequently rolled or hammered, and of a quality possessing considerable toughness and ductility, together with a statement of all the tests to which it has been subjected.

18. The heaviest engines in use on railways afford a measure of the greatest moving loads to which a bridge can be subjected. These rules apply equally to the main and the transverse girders. The latter should be calculated for the heaviest weights carried by the driving-wheels of locomotive engines.

19. It is desirable that viaducts should, as far as possible, be wholly constructed of brick or stone, and in all such cases they should have parapet walls on each side, about 4 feet 6 inches in height above the level of the rails, and not less than 18 inches thick.

Where it is not practicable to construct the viaducts of brick or stone, and iron girders are made use of, it is considered best that in

important viaducts the permanent way should be laid between the main girders. If, however, in such viaducts the main girders are placed below the level of the rails, substantial parapets, about 4 feet 6 inches in height, must be provided; and as a further protection, substantial guards should be fixed outside, above the level of and as close to the rails as possible, but not so as to interfere with the steps or any of the working parts of the engine or trains.

In some cases similar guards may be required when viaducts are constructed of other materials than iron.

Where iron is made use of for the construction of the abutments or piers which are intended to support or carry the iron girders of high bridges and viaducts, it must be distinctly understood that these abutments or piers should not consist of cast-iron columns of small size, such as 12, 15, or 18 inches in diameter.

In all large structures of this kind the stability of the work must be such as will provide for a wind pressure of 56 pounds on the square foot.

20. The upper surfaces of the wooden platforms of bridges and viaducts should be protected from fire.

21. The joints of the rails should be secured by means of fish-plates, or by some other equally secure fastening. The weight of the cast-iron chairs on branch lines, or lines on which the traffic will be small and light, and where it will be worked by engines of ordinary construction, should not be less than 26 pounds each; but on main lines, and where heavy traffic may be worked at high speeds, the chairs should weigh not less than 28 pounds.

22. When chairs are used to support the rails they should be secured to the sleepers, at least partially, by iron spikes or bolts. With flat-bottomed rails, when there are no chairs, or with bridge rails, fang or other through-bolts should be used, at least at the joints and at some intermediate places.

23. No standing work (other than a passenger platform) should be nearer to the side of the widest carriage in use on the line than 2 feet 4 inches, at any point between the level of 2 feet 6 inches above the rails and the level of the upper parts of the highest carriage doors. This applies to all arches, abutments, piers, supports, girders, tunnels, bridges, roofs, walls, posts, tanks, signals, fences, and other works, and to all projections at the side of a railway constructed to any gauge.

24. The intervals between adjacent lines of rails, or between lines of rails and sidings, should not be less than 6 feet.

25. At all level crossings of turnpike and public roads the gates should be so constructed as to close across the railway, as well as across the road, at each side of the crossing, and a lodge or station-house should be provided, as is required by Act of Parliament. The gates should not be capable of being opened at the same time for the road and the railway, and all sidings and connections should be placed so that the shunting can be done without interfering with the level crossing. When a level crossing occurs at a station, there should be a box, if there is not a lodge, at the gates, for the use of the gate-keeper, unless the gates are worked from a signal cabin. Wooden gates are considered preferable to iron gates for closing across the railway.

26. The fixed signals attached to the gates at the level crossings should be placed in convenient positions for being seen along the railway as well as along the road. When a level crossing is so situated that an approaching train cannot be seen from a sufficient distance, distant-signals (which may both be worked by one lever) should be supplied.

27. Mile-posts and quarter and half-mile posts and gradient-boards should be provided along the line.

28. Tunnels and long viaducts should in all cases be constructed with recesses for the escape of the plate-layers.

29. In all curves where the radius is 10 chains or less, a check-rail should be placed inside the inner rail of the curve.

C.

MODES OF WORKING SINGLE LINES.

In the case of a line being single, a certificate, under the seal, and signed by the chairman and secretary of the company, should be sent to the Board of Trade, through the inspecting officer, to the effect that one of the two following modes of working single lines will be adopted, namely :

I.—That only one engine in steam, or two or more engines coupled together, shall be allowed to be upon the single line at one and the same time.

II.—That the line shall be worked by train-staff, in the mode described in the following amended regulations, combined with the absolute block-telegraph system :

RULES FOR WORKING THE SINGLE LINE BETWEEN A, B, C, &c.

1. Either a train-staff or a train-ticket is to be carried with each engine or train to and fro, and for this purpose

[One, two or more] train-staffs and sets of train-tickets will be employed, viz. :

	Color of Staff and Ticket.	Form of Staff and Ticket.
One between A and B...........	Red.	Square.
One between B and C............	Blue.	Round.
&c., &c.	&c.	&c.

2. No engine or train is to be permitted to leave or pass either of the staff-stations A, B, or C, unless the staff for the portion of line over which it is to travel is then at the station ; and no engineman is on any account to leave or pass a staff-station without seeing such train-staff.

3. If no second engine or train is intended to follow, the staff is to be given to the engineman or guard.

4. If other engines or trains are intended to follow before the staff can be returned a train-ticket, stating "staff following," is to be given to the engineman of the leading engine, or the engineman or guard of the leading train, and so on with any other except the last, the staff itself being sent with the last. After the staff has been sent away, no other engine or train is to leave the staff-station under any circumstances whatever until its return.

5. The train-tickets are to be kept in a box fastened by an inside spring, and the key to open the box is the train-staff, so that a ticket cannot be obtained without the train-staff. The train-staff is to lock the box in being taken out of it.

6. The train-staffs, the train-tickets, and the ticket-boxes are to be painted or printed in different colors, red for the line between A and B ; blue for that between B and C, &c.; the inside springs and the keys on the staffs being so arranged that the red staff cannot open the blue box, nor the blue staff the red box, and so forth. This is to prevent mistakes.

7. The ticket-boxes are to be fixed by brackets in the booking-offices at the staff-stations, the brackets being turned up at the ends to receive the train-staffs when they are at the stations.

8. The clerk in charge, the inspector, or the person in charge for the time at a staff-station, is the sole person authorized to receive, exhibit, or deliver the staff or ticket.

9. The usual special train tail-signal, "engine following," is to be used when a ticket is given, for the guidance of the platelayers and gate-keepers upon the line.

10. When a ballast train has to work on the line, the staff is to be given to the engineman or guard in charge of it. This will close the line whilst the ballast train is at work. The ballast train must proceed afterwards to one of the staff stations to open the line before the ordinary traffic can be resumed.

11. In the event of an engine or train breaking down between two staff-stations, the fireman is to take the train-staff to the staff-station in the direction whence assistance may be expected, that the staff may be at that station on the arrival of an engine. Should the engine or train that fails be in possession of a train-ticket instead of the staff, assistance can only come from the station at which the train-staff has been left. The fireman will accompany any assisting engine to the place where he left his own engine.

N. B.—The train-staff may either be fixed in a socket on the engine or tender, or carried over the shoulder by means of a cross-belt.

D.

PRECAUTIONS RECOMMENDED IN THE WORKING OF RAILWAYS.

1. There should be a break-vehicle with a guard in it at the tail of every train; this vehicle should be provided with a raised roof and extended sides, glazed to the front and back; and it should be the duty of the guard to keep a constant look-out from it along his train.

2. All passenger carriages should be provided with continuous foot-boards extending throughout the whole length of each carriage and as far as the outer ends of the buffer castings. As passenger carriages now pass from one company's line to another's, it is essential for the public safety that, although the widths of the carriages on the different lines differ from each other, the widths across the carriages from the outside of the continuous foot-board on one side to the outside of the continuous foot-board on the opposite side should be identical for the carriages of all railway companies, so that the lines of rails may be laid at the proper distance from the edges of the passenger platforms.

3. There should be means of intercommunication between a guard at the tail of every passenger train and the engine-driver, and between the passengers and the servants of the company, as required by the Legislature.

4. Continuous breaks under the control of the engine-driver and each guard should be employed with all passenger trains. In the opinion of the Board of Trade, which has been fully expressed in recent correspondence, due security will not have been taken for the public safety until some system or systems of continuous breaks has or have been universally adopted, instantaneous in action, capable of being applied by engine-driver or guard, and automatic in case of accident.

5. The tires of all wheels should be so secured to the rims of the wheels as to prevent them from flying open when they are fractured.

6. The engines employed with passenger trains should be of a steady description, with not less than six wheels, with a long wheel-base, with the centre of gravity in front of the driving wheels, and with the motions balanced. They should not be run tender or tank first.

7. Records should be carefully kept of the work performed by the wearing parts of the rolling stock, to afford practical information in regard to them, and to prevent them from being retained in use longer than is desirable.

8. All lines should be worked on the block telegraph system. In case of junctions the block system should be employed for preventing trains which can come into collision through overrunning signals, from approaching a junction simultaneously. The signal cabins should be commodious, and should be supplied with clocks, with record books, with a separate needle for signaling the trains on each line of rails, and with an extra needle for other necessary communications between the signalmen. The telegraph instruments and signal handles should face the directions in which they work.

9. When drovers or other persons are permitted to travel with goods or cattle trains, suitable vehicles should be provided for their accommodation near the front of such trains.

10. Luggage should not be carried on the roofs of railway carriages.

11. The names of the stations should be marked on the lamps, besides being shown on other conspicuous places.